DEVELOPMENT OF COMPACT VARIABLE-VOLTAGE, BI-DIRECTIONAL 100KW DC-DC CONVERTER

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Outline

- Project goals
- Power Stage Design
- DSP controller, interface circuit and gate driver implementation
- Power stage layout and packaging
- Converter testing
- Summary and Conclusions

Project Goals

Bidirectional dc-dc converter targets:

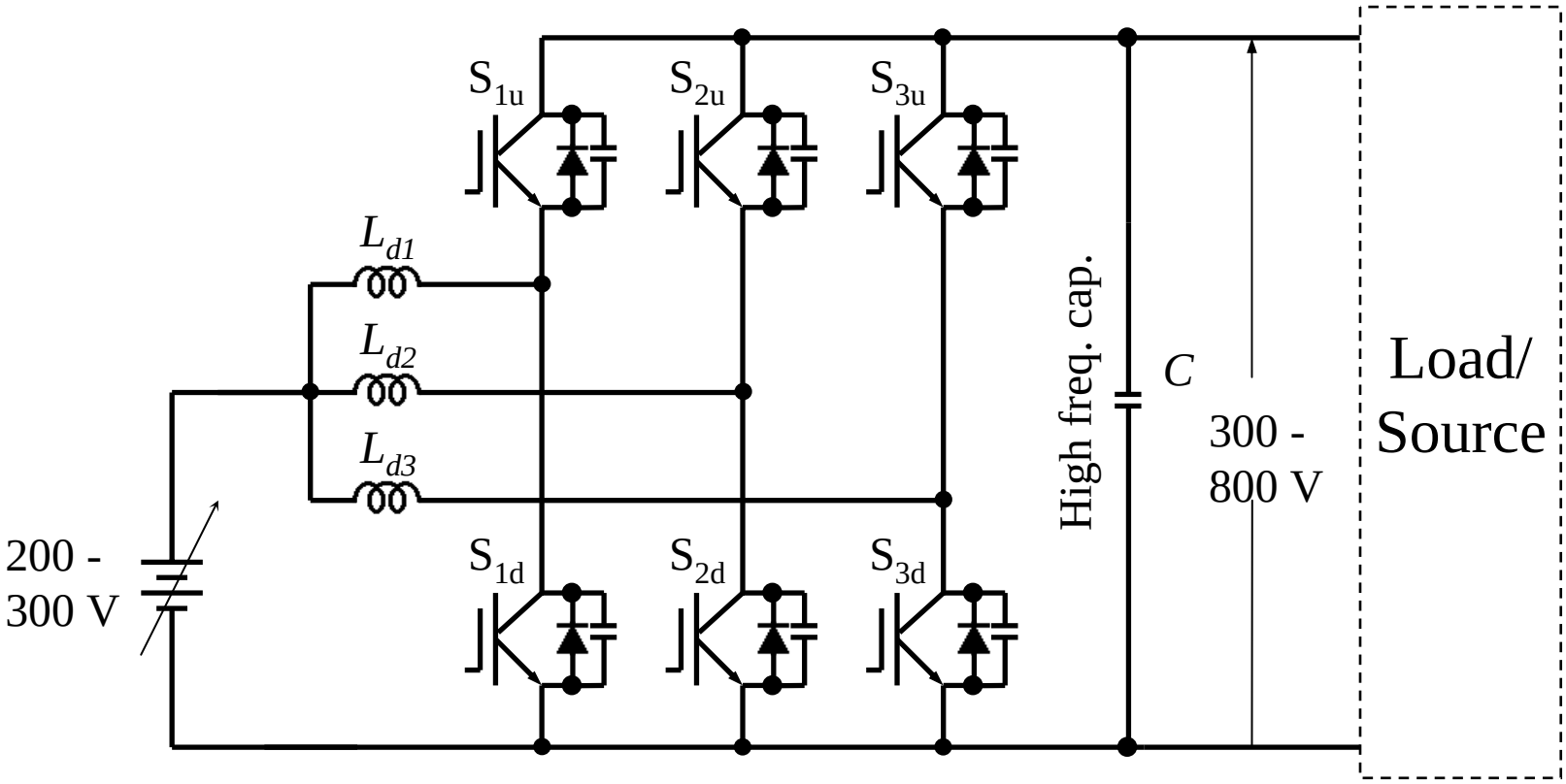
- Input voltage range: 200 - 300 VDC (battery pack voltage)
- Output voltage range: 300 - 600 VDC
- Bidirectional power flow Continuous Power: 100 kW, Peak: 150kW
- Power density: 4 to 8 kW/liter
- Specific power density: 4 to 6 kW/kg
- Total efficiency: ≥ 95%
- SVM frequency: ~20kHz
- Coolant Temperature: ≥ 90^{o}C

Innovations

- A novel yet simple zero-voltage soft-switching scheme
  - without adding any extra switch
  - making a 25KHz switching frequency possible
- High-end digital signal processor controller
  - allow fast and smooth mode transition
- An interleaving 3-phase design
  - substantially reducing the ripple current and filter capacitor size
- Nano-inductor design
  - High permeability, high saturation flux density lead to small inductor size
- SiC Schottky diode-Si IGBT power modules
  - Minimized thermal resistance
  - Robust diodes, zero-recovery charge

POWER STAGE DESIGN

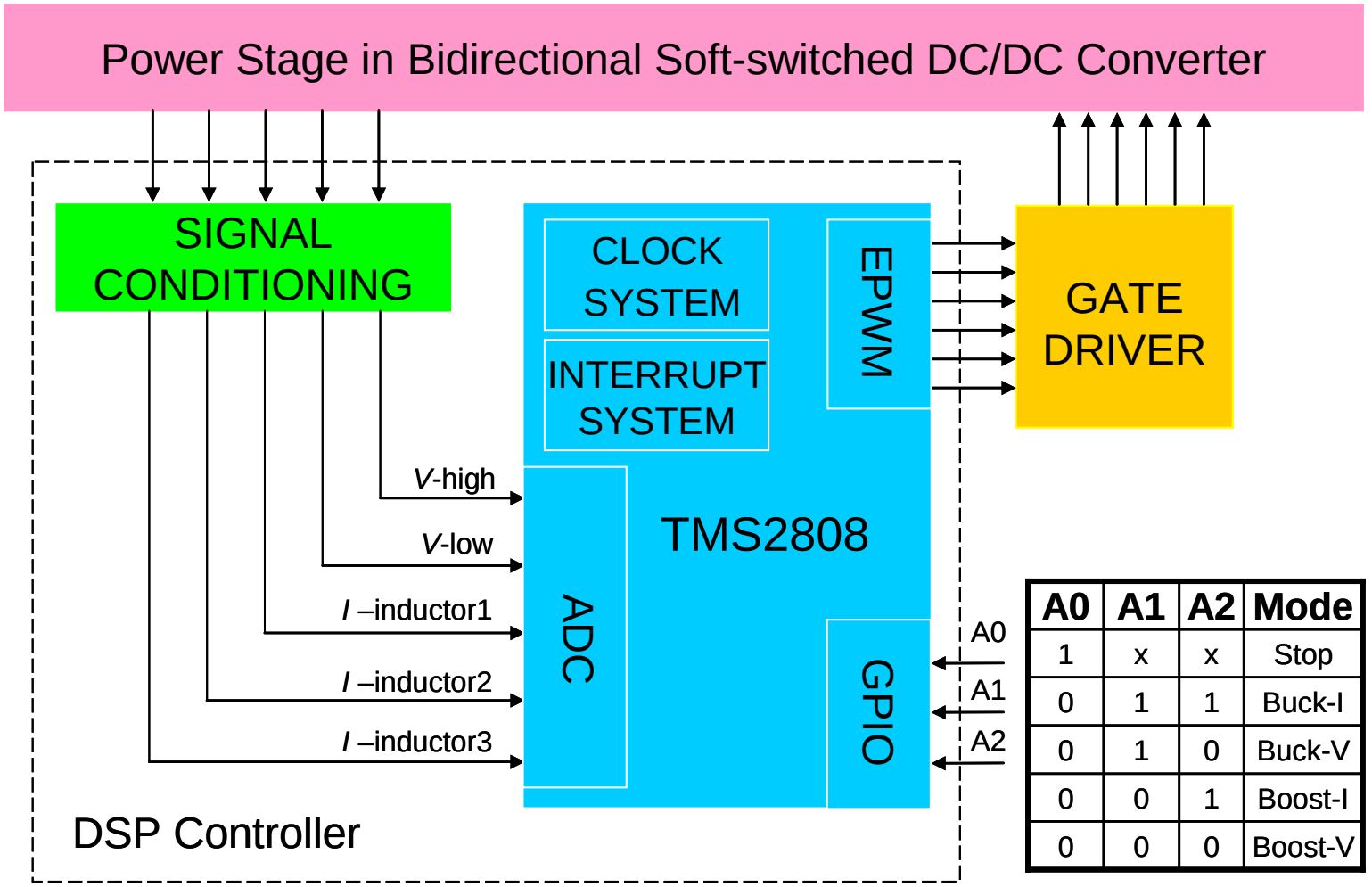
Proposed Soft-switching Bi-directional DC/DC Converter with Lossless Snubbers



A special switching scheme that utilizes unused switches to perform soft switching:

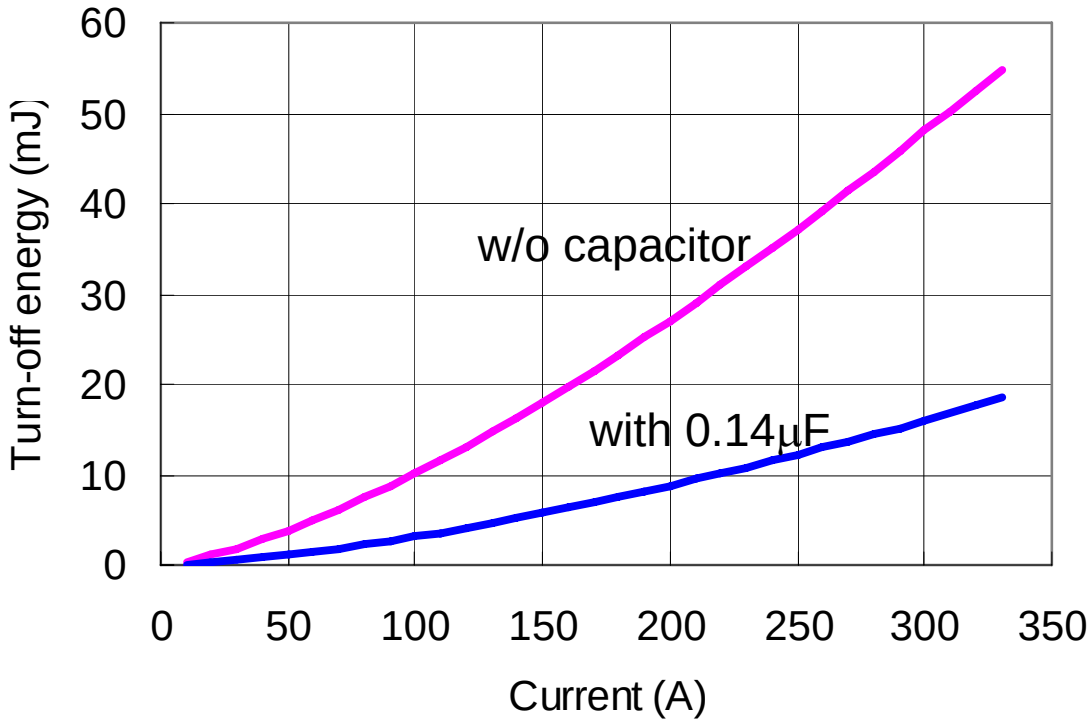
The basic idea is to have the unused switch turned on while the active switch is turned off. This will allow current continuously flow in opposite direction, thus avoiding the discontinuous current and parasitic ringing. Now to reduce the turn-off loss, we can put the lossless snubber across the device to slow down the rate of switching.

Overall hardware system structure: power stage, gate driver and DSP controller



A0	A1	A2	Mode
1	x	x	Stop
0	1	1	Buck-I
0	1	0	Buck-V
0	0	1	Boost-I
0	0	0	Boost-V

Summary of Testing Results of IGBT Loss



V_{DC}=700V,
C_{snub}= 0.14μF

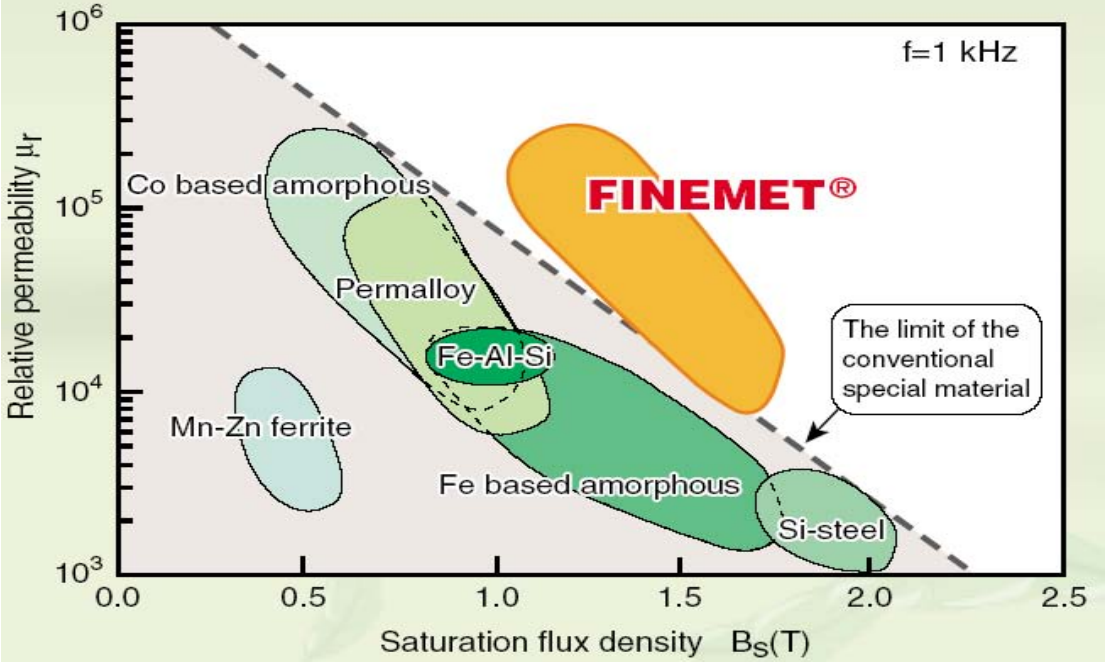
×3 loss reduction

Achieved without extra switches/inductors

Inductor Design

Superior to Conventional Material

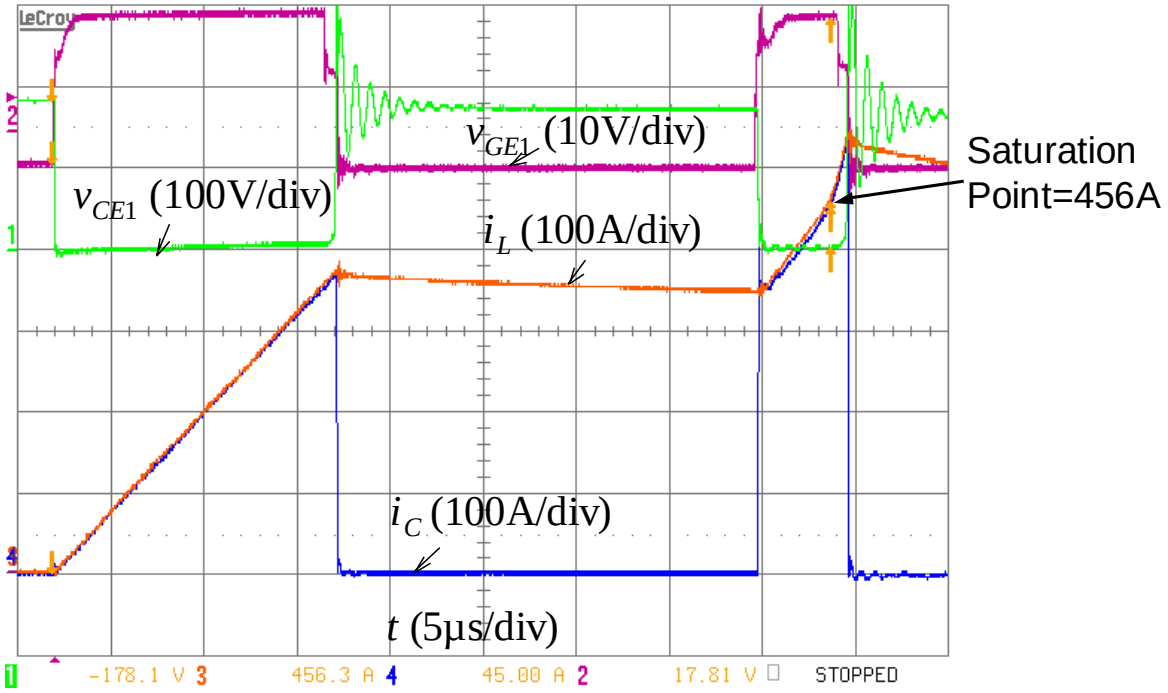
Relationship between relative permeability and saturation flux density of various soft magnetic materials



A superior core, FINEMET®, is used
High permeability, high flux density

Inductor Design Verification

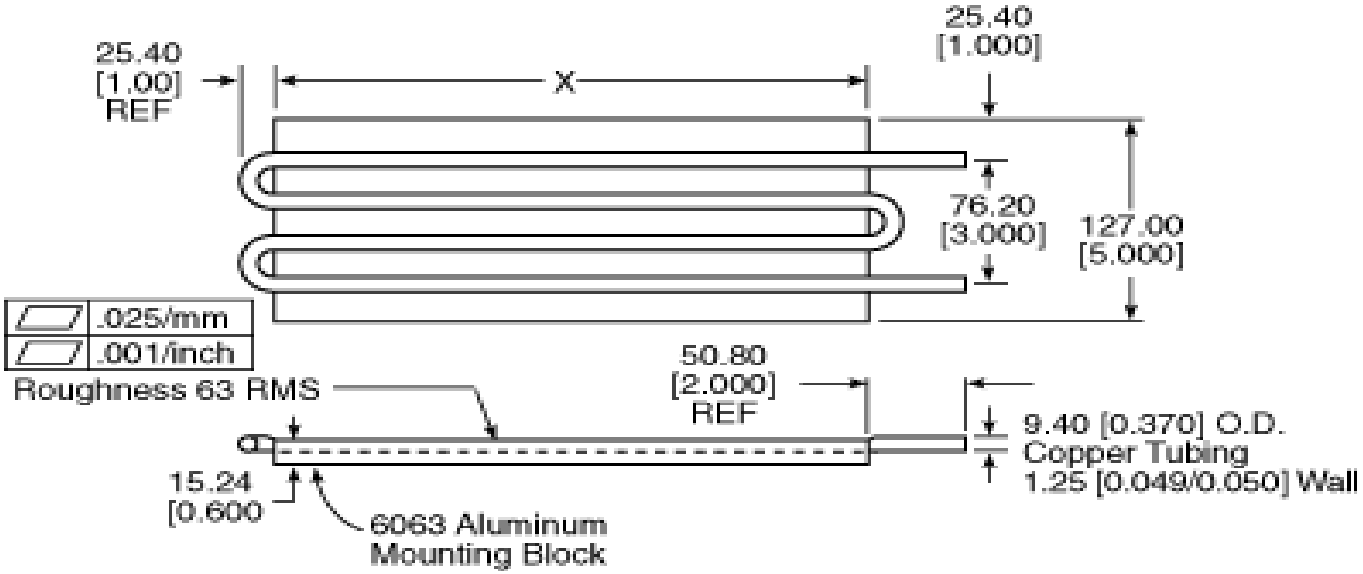
L=14.5μH, I_{SAT}=456A, 20% design margin



Each inductor core:

3.35kg, 0.47 liter

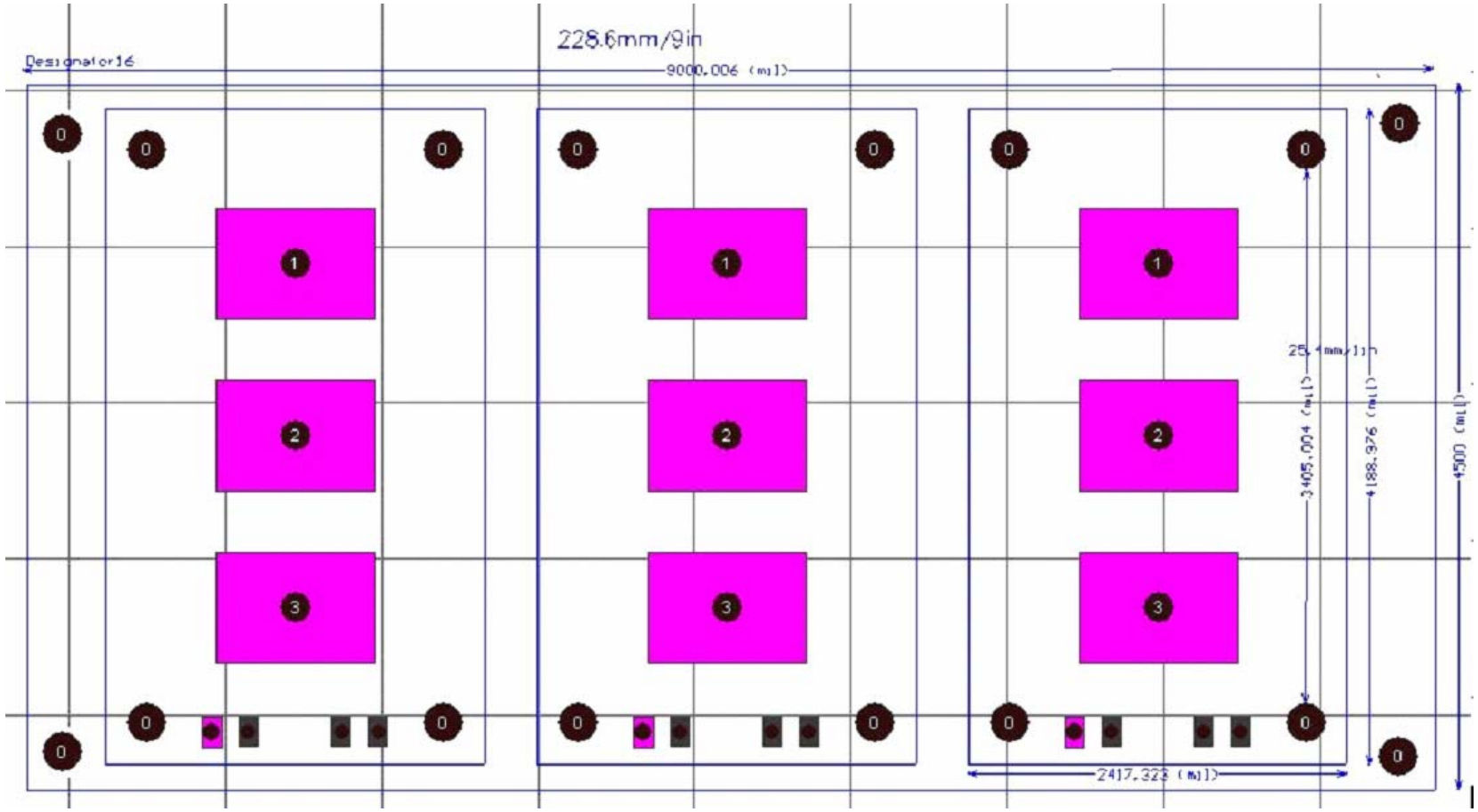
Liquid cooled heatsink design



Liquid-cooled

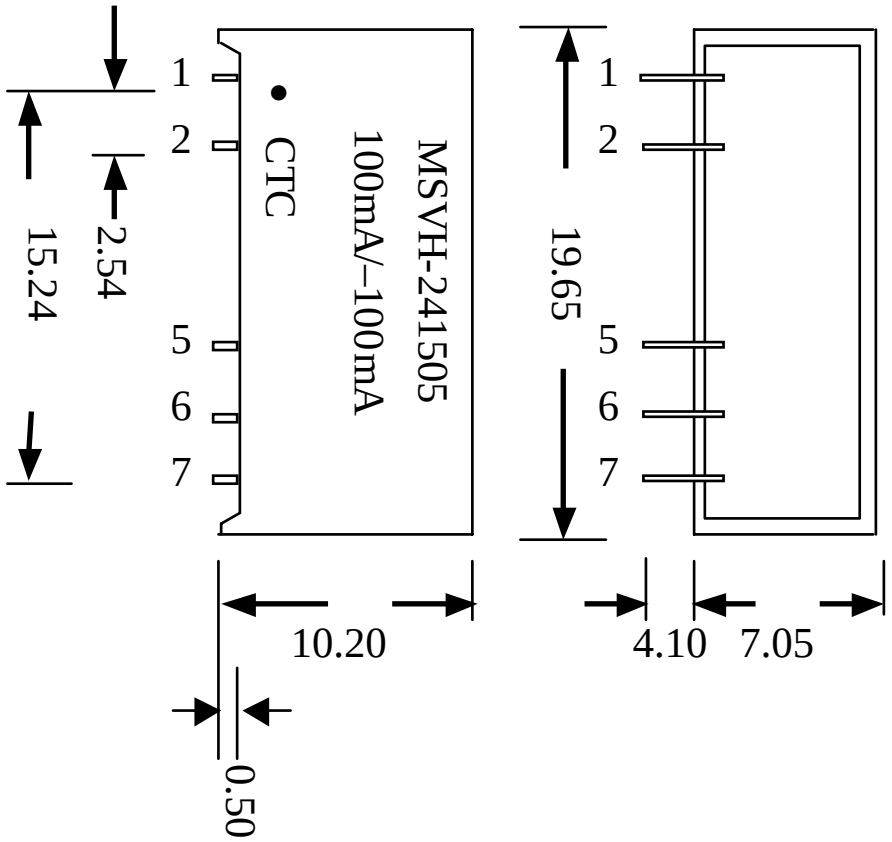
θ_{th}<0.01°C/W

Physical Layout Dimensions of IGBTs



DSP controller, interface circuit and gate driver implementation

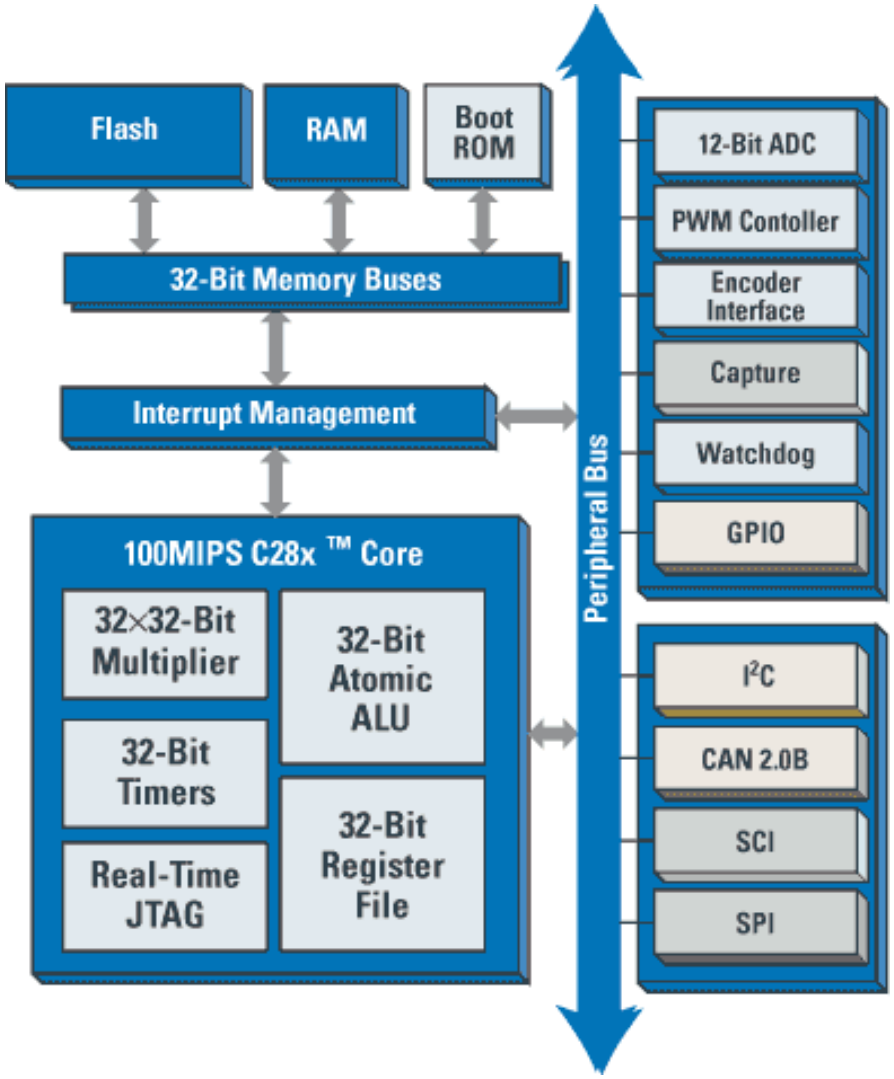
Auxiliary Gate Drive Power Supply



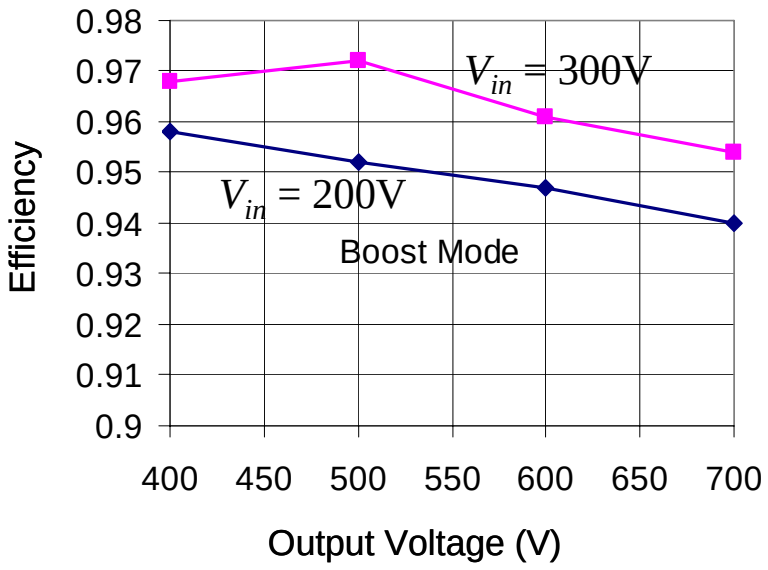
Pin no	Function
1	+Vin
2	–Vin
5	–Vout
6	COM
7	+Vout

The gate driver power supply module provides isolated outputs of +15V and –5V at ⩾90°C.

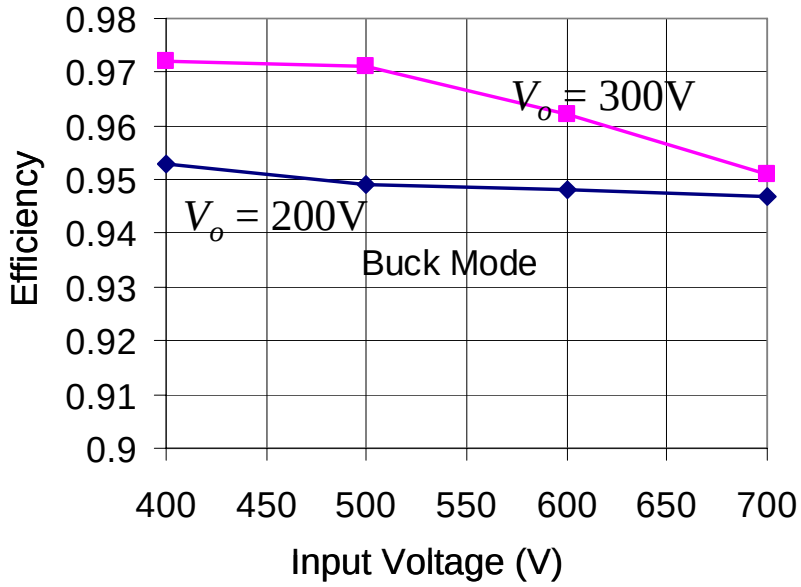
DSP TMS320F2808 function blocks



Simulation results for the efficiency of boost mode and buck mode



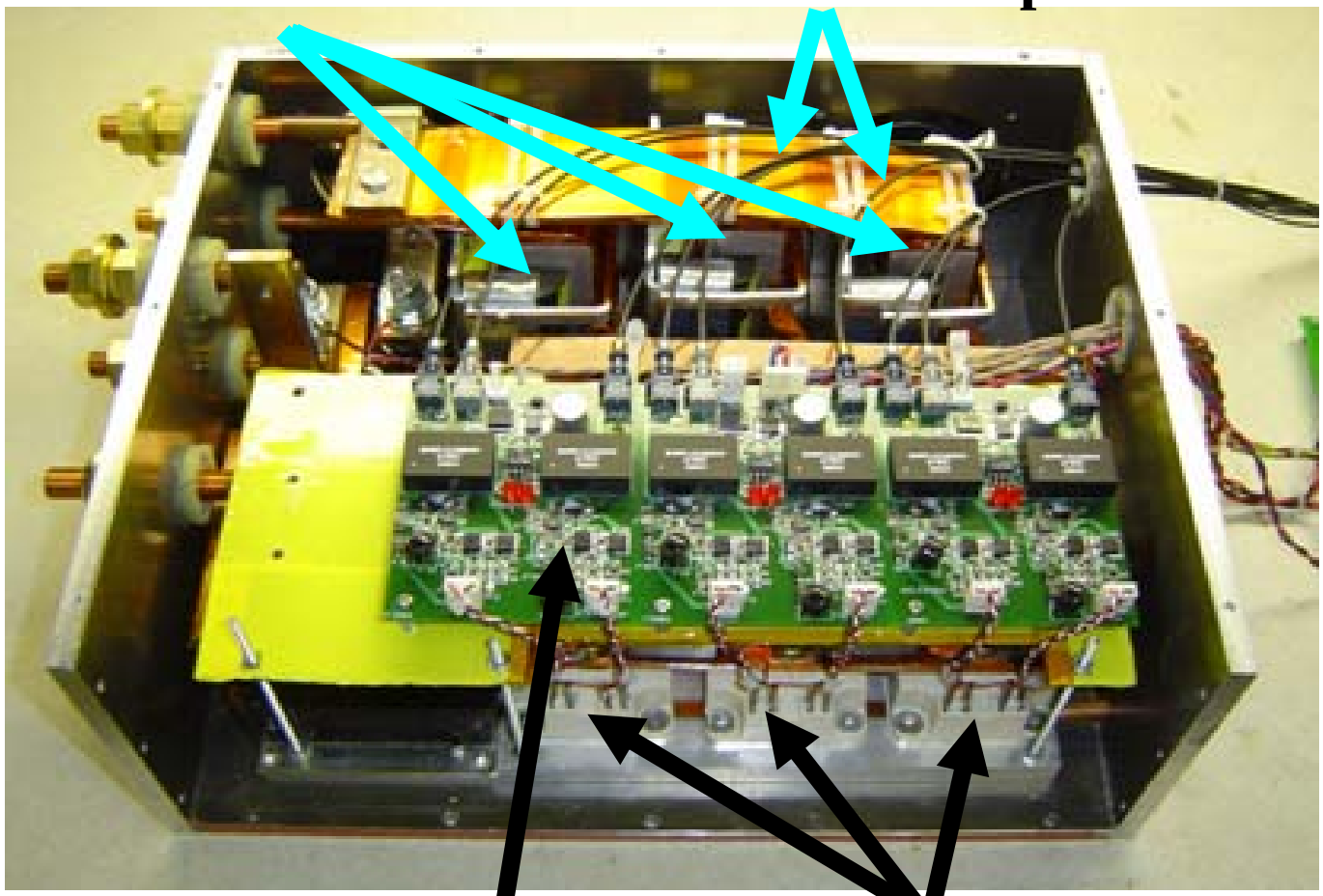
Boost mode efficiency



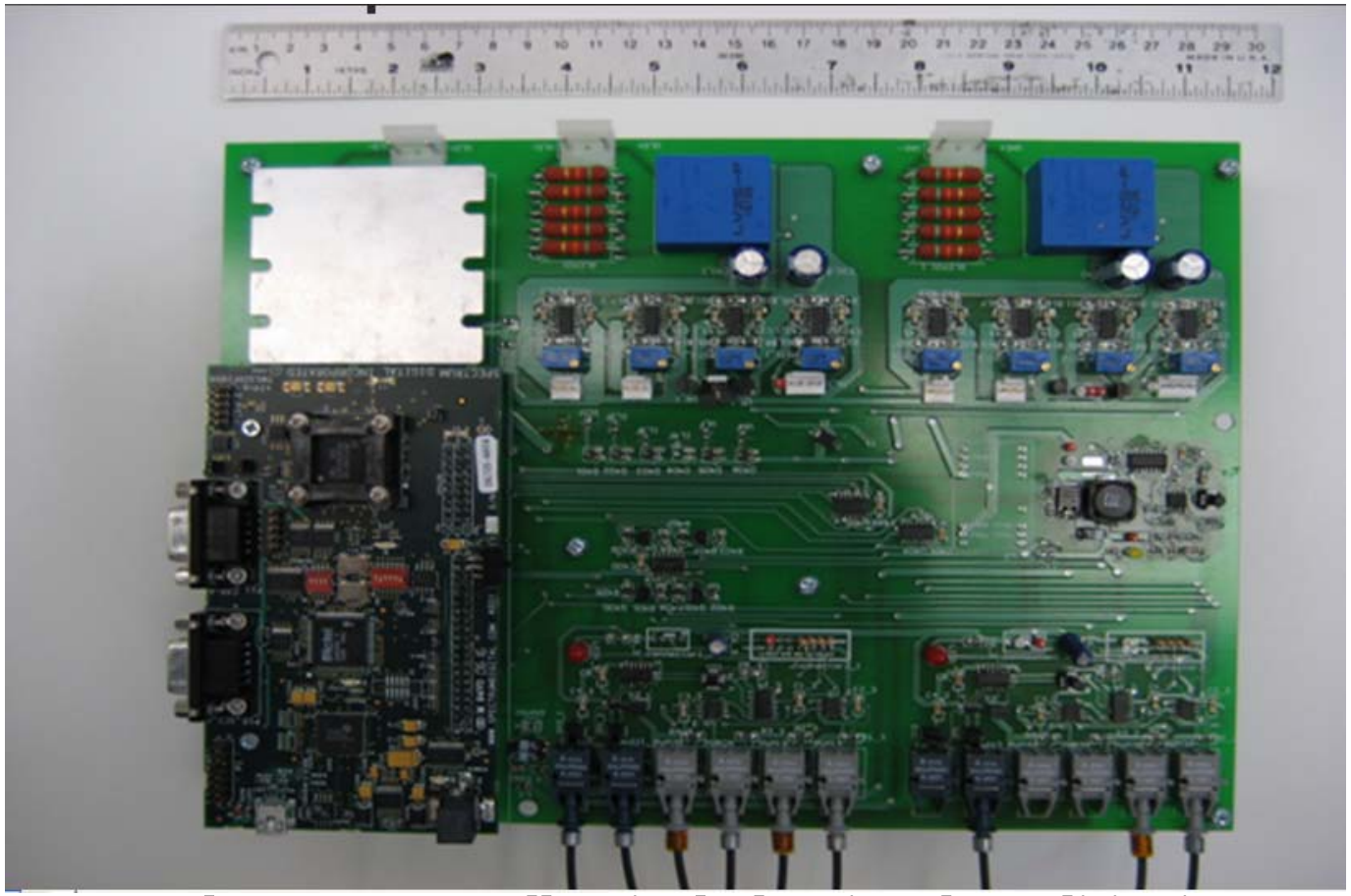
Buck mode efficiency

Power stage layout and packaging

Converter module

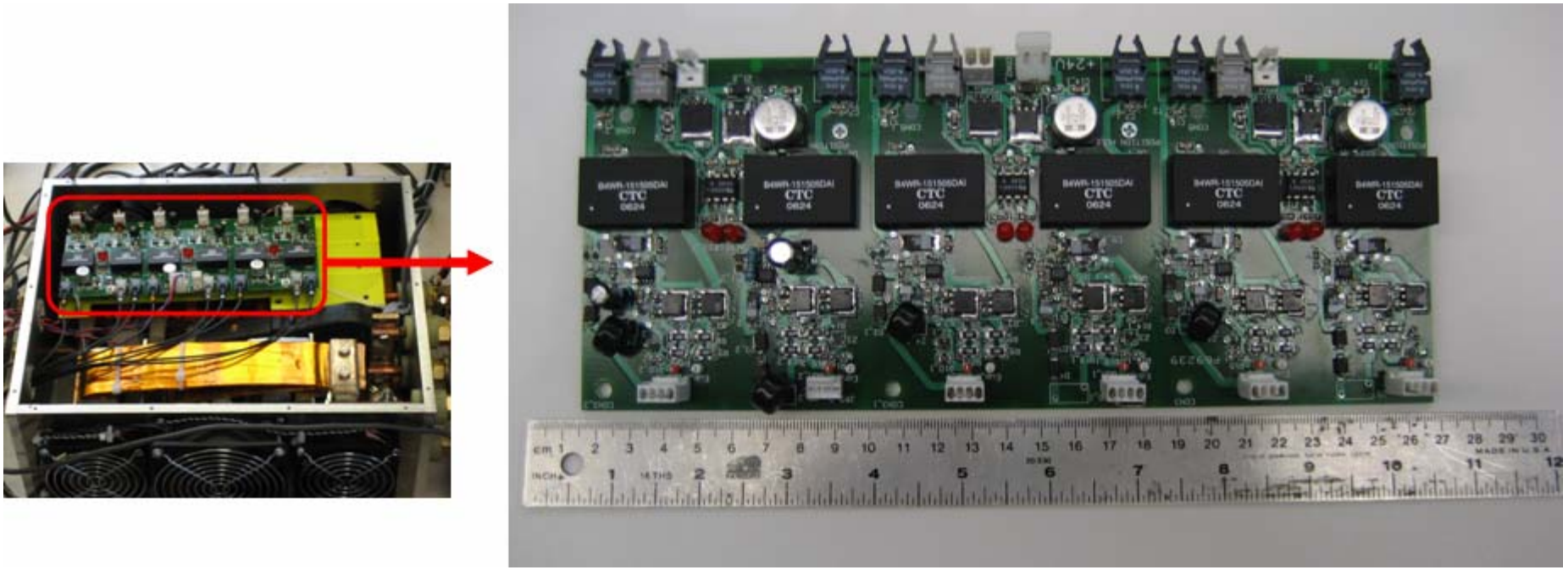


DSP controller with interface board



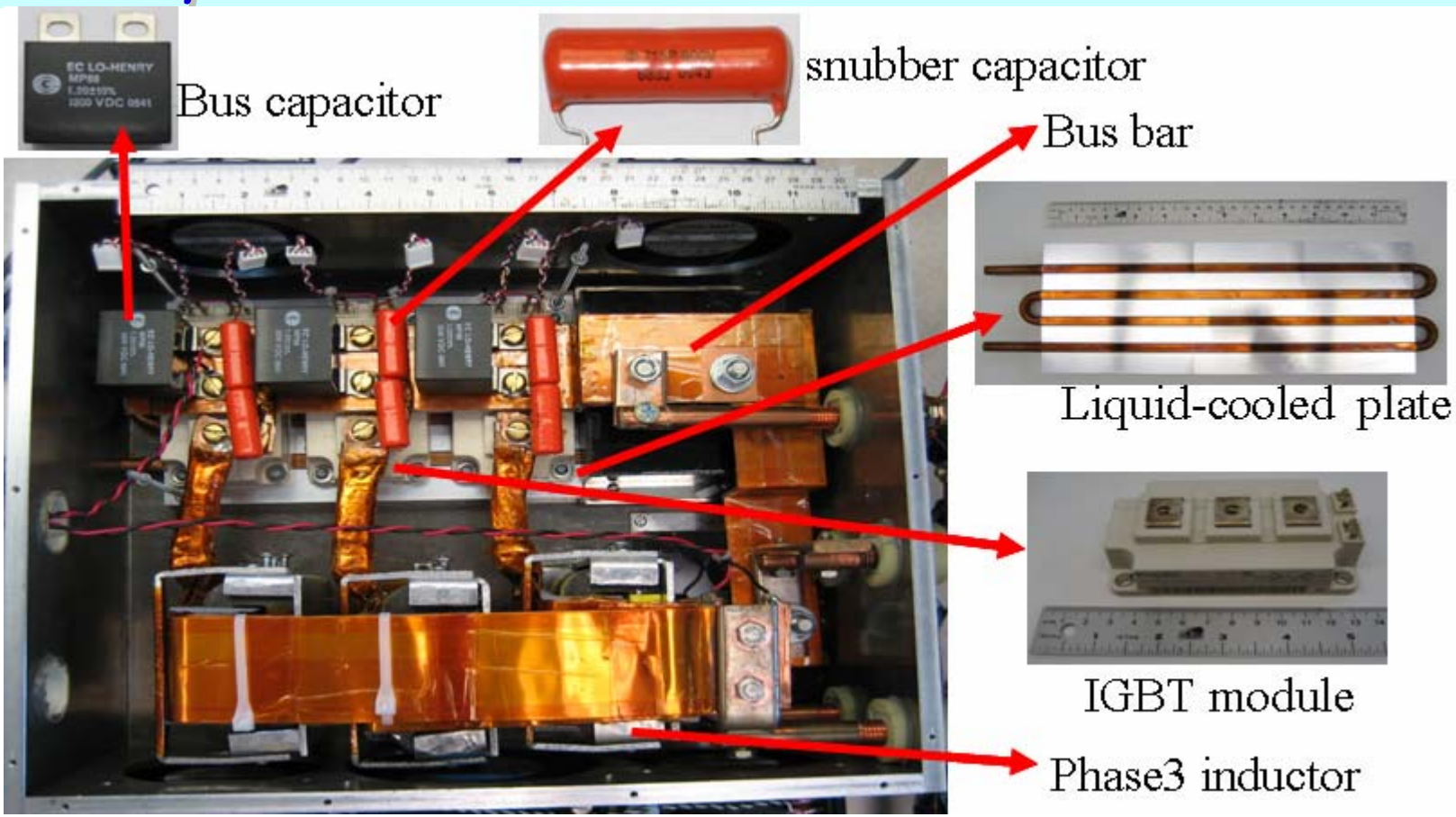
- **The DSP controller includes signal conditioning circuit and TMS320F2808 digital signal processor.**

The IGBT driver circuit



- Provides electrical isolation by optocouplers, fiber optics, and by transformers
- With overcurrent detection and pulse-by-pulse overcurrent protection function

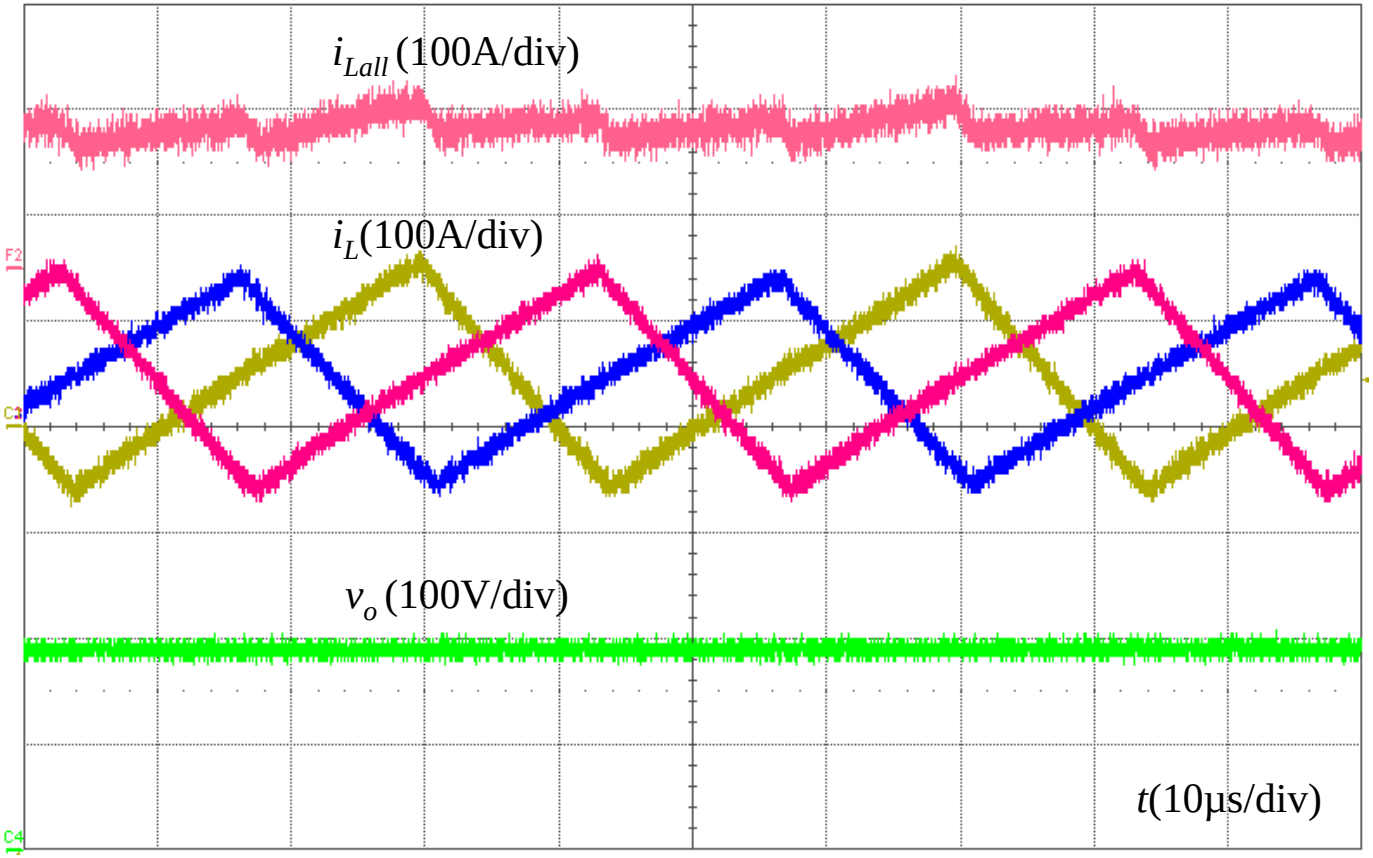
The Power Stage Layout



- With minimized size of the inductors for 100kW output power
- Zero-voltage switching on and zero-voltage switching off with capacitor
- Compact bus capacitor size with Interleaving ripple cancellation

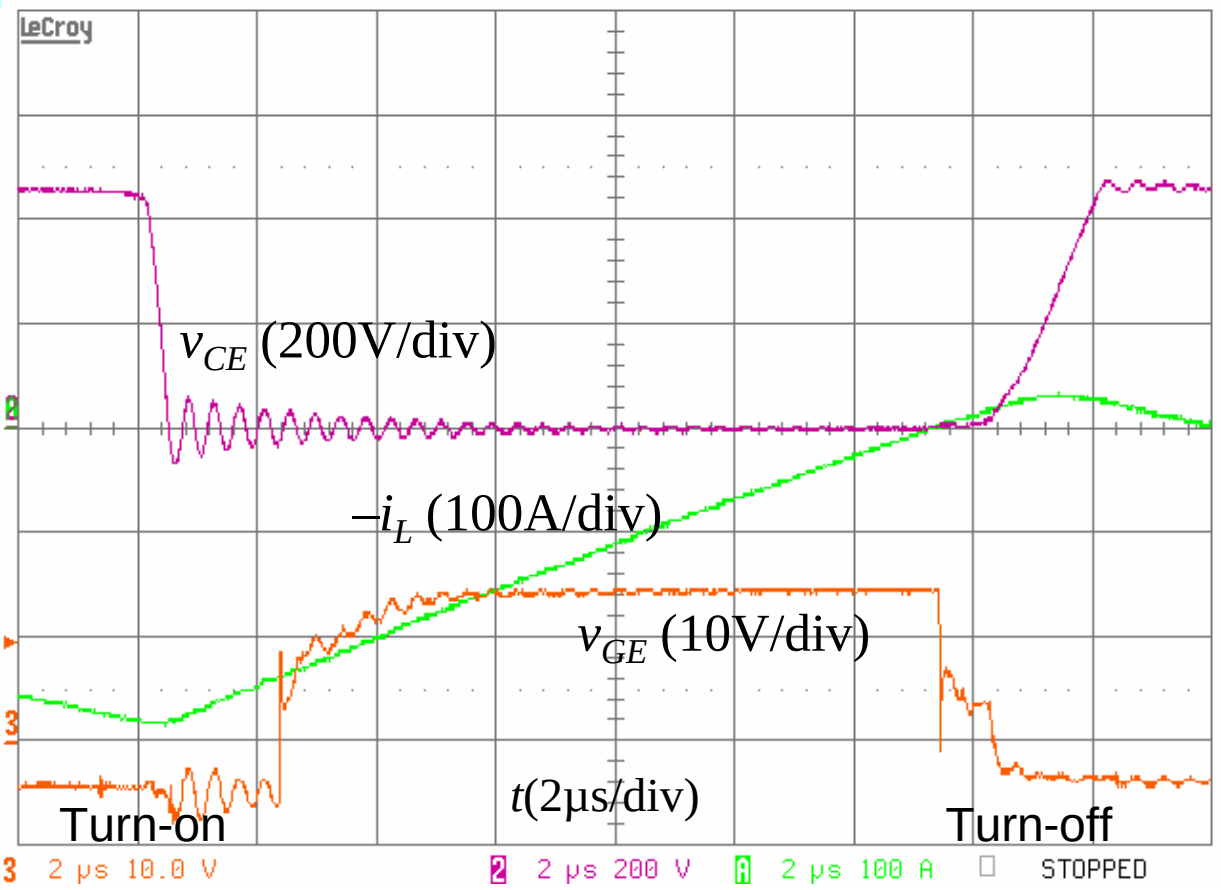
Converter testing with Coolant at 90°C

Measured Current Waveforms



Inductor current ripple is greatly reduced by interleaving three phases

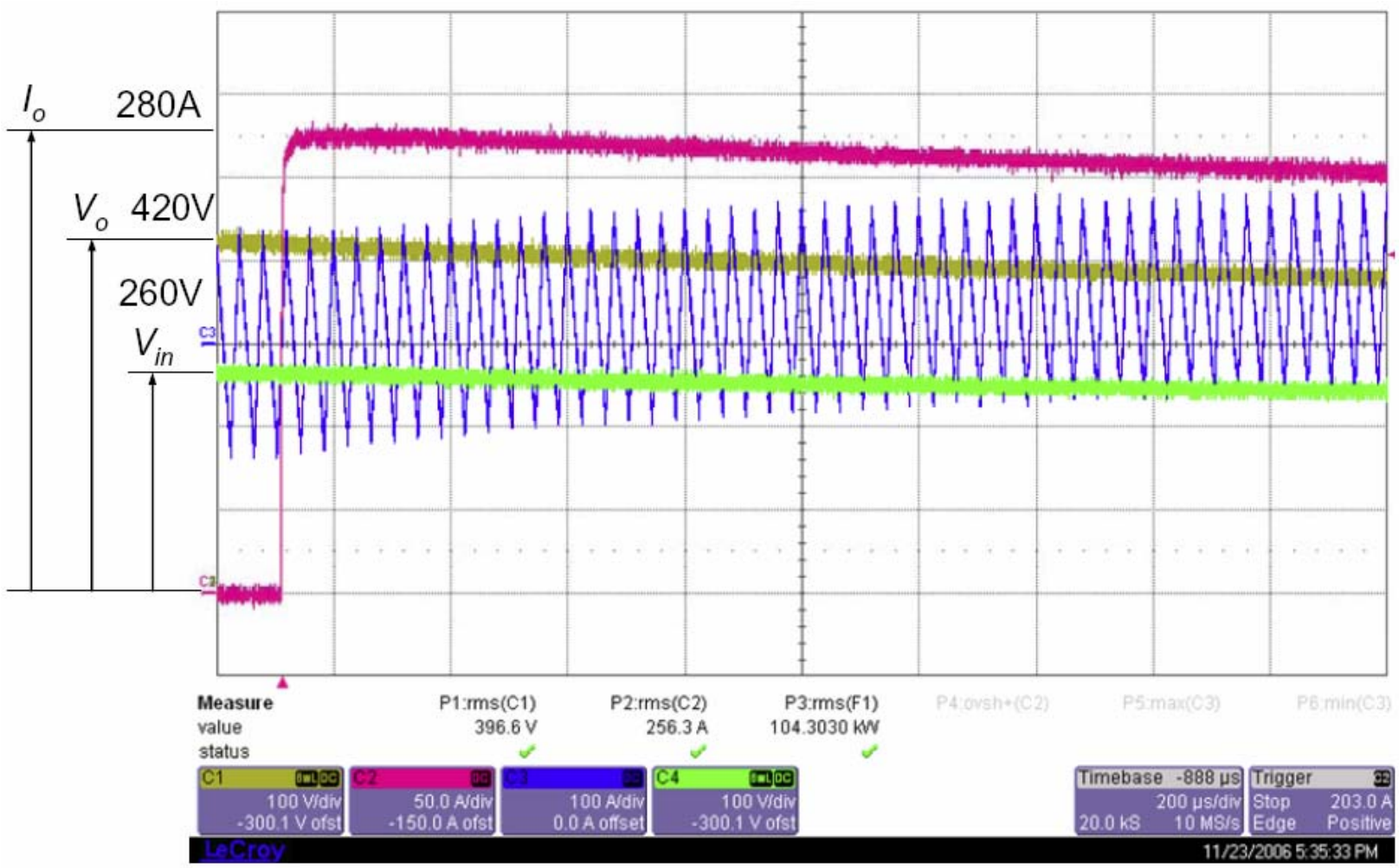
Detailed Measured Waveforms in 100kW Load



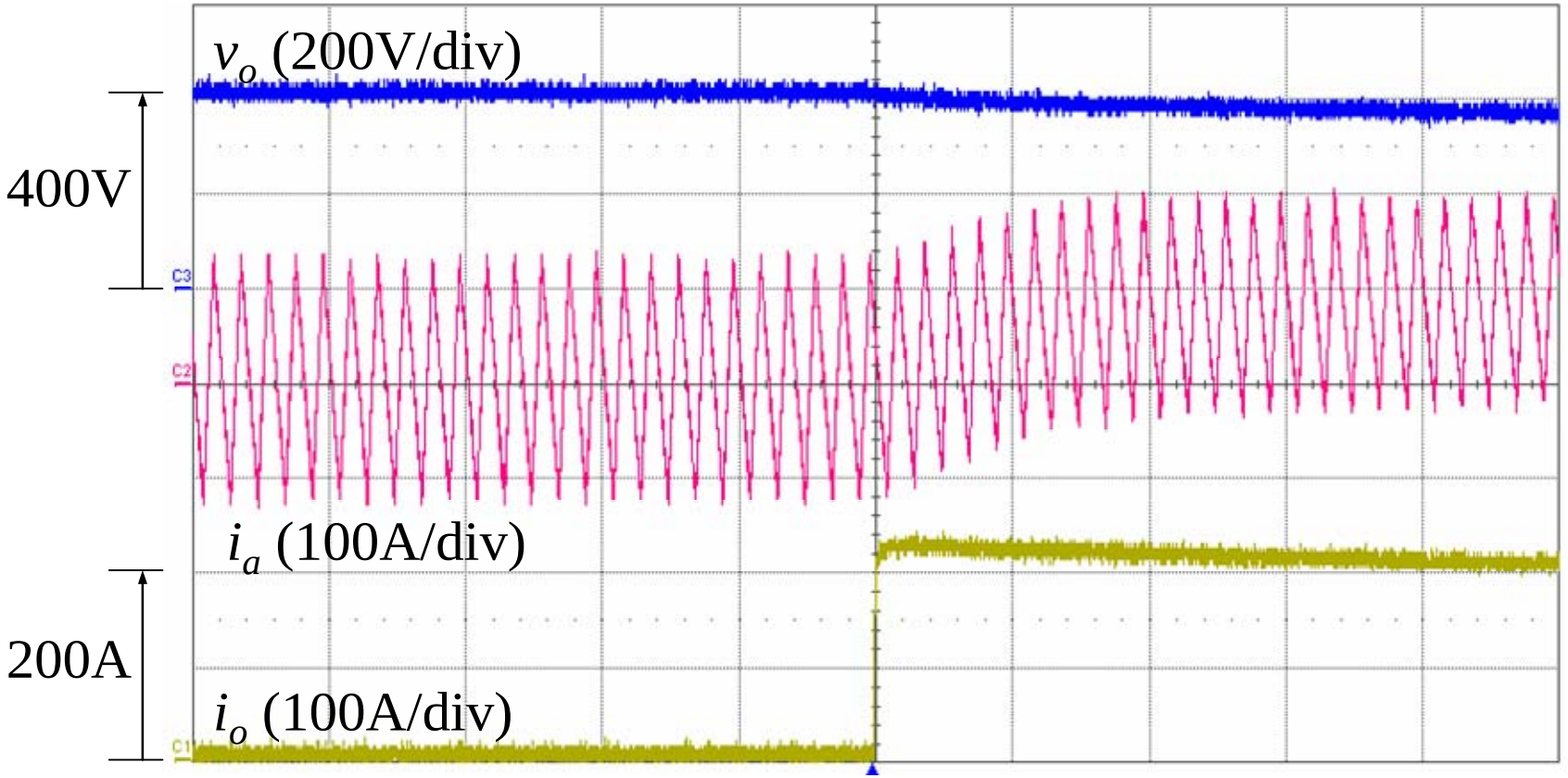
Test condition : Vin=450V, Vout=280V, P=100KW

- Note that Inductor current negated.
- Switch is turned on under ZVS condition.

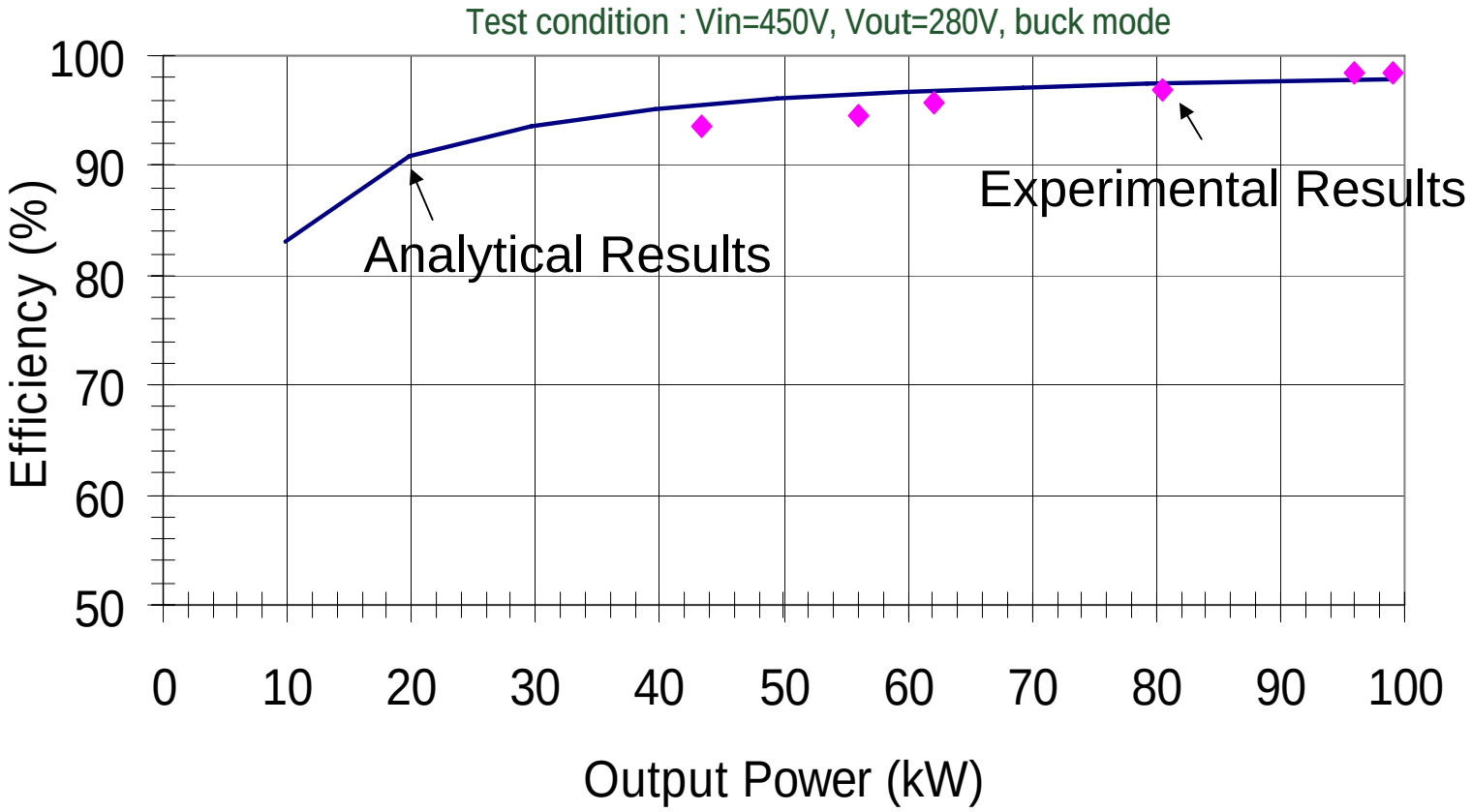
Start-up Voltage and Current Waveforms at 108-kW Operation in Boost Mode



Transient response of the converter under boost mode operation with a step load change from no load to 80-kW

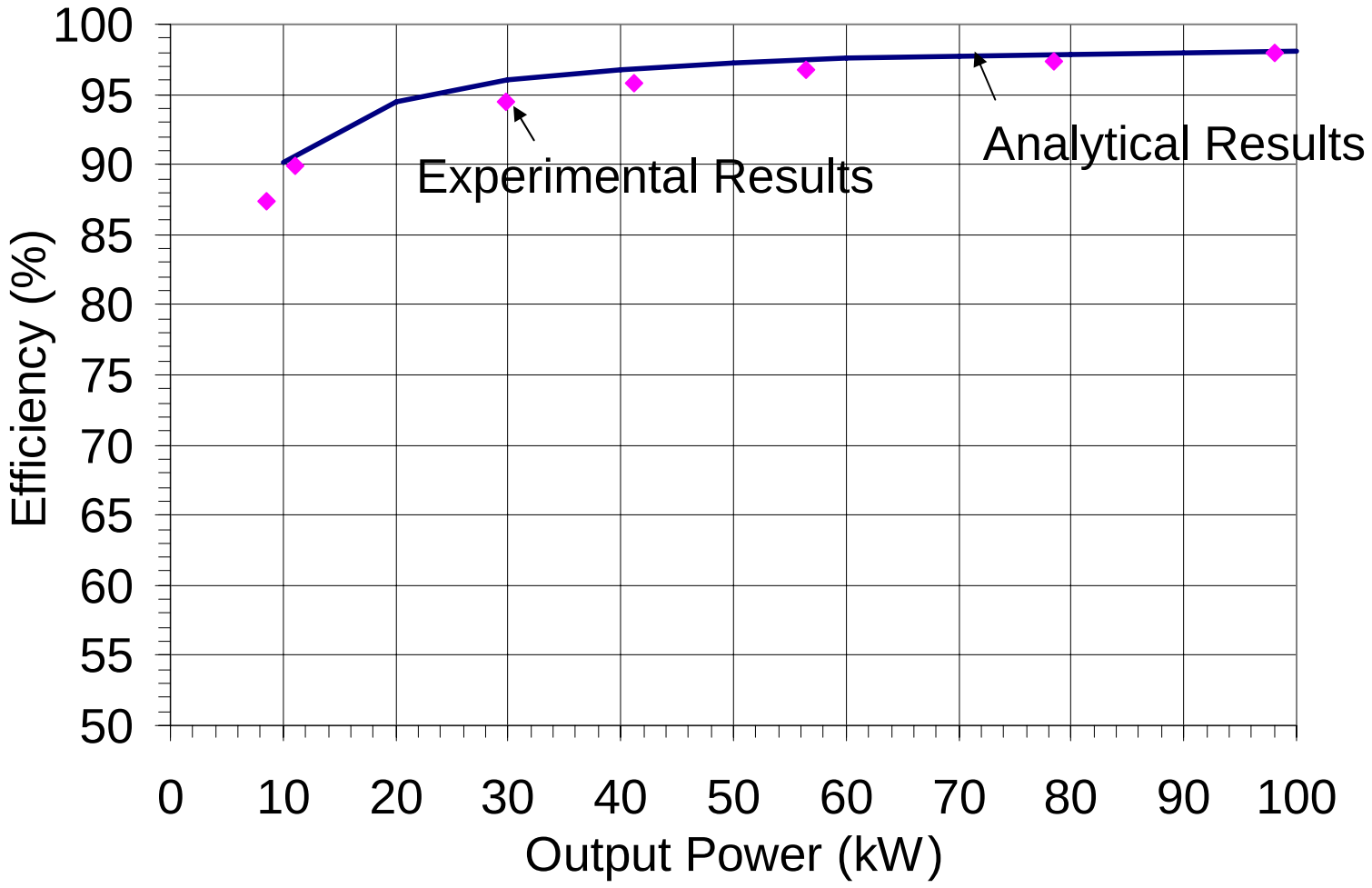


Experimental efficiencies in Buck Mode (450V input and 280V output)



- Maximum efficiency is around 97%

Experimental efficiencies in Boost Mode (240V input and 360V output)



- Maximum efficiency is around 98%

Summary

- Si-based soft-switching bidirectional DC-DC converter has been successfully demonstrated
  - Novel soft-switching circuit without extra switch/inductor
  - DSP (TI-TMS320F2808), inductor, gate driver, optical fiber interface designed
- Successfully tested at 90°C temperature for 30-kW continuous and 108-kW.
- Efficiency of 97-98% achieved in both buck and boost modes
- Compact size (less than 25 liters) demonstrated
- SiC/Si hybrid power modules being packaged for DC-DC converter operating at high coolant temperature >90^{o}C
- Six phase interleaved design will reduce stress to inductors for robust long-term reliable DC-DC converter for FCS